OPTIMIZED BUBBLE UP RECEIVER
AMR SYSTEM

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CLAIM TO PRIORITY

The present application claims priority to United States Provisional Patent Application No. 60/500,506, (Attorney Docket No. 1725.159US01), filed on September 5, 2003, and entitled "OPTIMIZED BUBBLE UP RECEIVER".

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RELATED APPLICATIONS

This application is related to commonly assigned U.S. Provisional Application No. 60/500,507 (Attorney Docket No. 1725.173US01), filed on September 5, 2003, entitled "SYSTEM AND METHOD FOR DETECTION OF SPECIFIC ON-AIR DATA RATE," U.S. Provisional Application No. 60/500,515 (Attorney Docket No. 1725.162US01), filed September

15 5, 2003, entitled "SYSTEM AND METHOD FOR MOBILE DEMAND RESET," U.S. Provisional Application No. 60/500,504 (Attorney Docket No. 1725.160US01), filed September 5, 2003, entitled "SYSTEM AND METHOD FOR OPTIMIZING CONTIGUOUS CHANNEL OPERATION WITH CELLULAR REUSE," U.S. Provisional Application No. 60/500,479 (Attorney Docket No. 1725.156US01), filed September 5, 2003, entitled "SYNCHRONOUS

20 DATA RECOVERY SYSTEM," U.S. Provisional Application No. 60/500,550 (Attorney Docket No. 1725.161US01), filed September 5, 2003, entitled "DATA COMMUNICATION PROTOCOL IN AN AUTOMATIC METER READING SYSTEM," U.S. Patent Application No. 10/655,760 (Attorney Docket No. 10145-8011.US00), filed on September 5, 2003, entitled "SYNCHRONIZING AND CONTROLLING SOFTWARE DOWNLOADS, SUCH AS FOR

COMPONENTS OF A UTILITY METER-READING SYSTEM," U.S. Patent Application No. 10/655,759, (Attorney Docket No. 10145-8012.US00) filed on September 5, 2003, entitled "FIELD DATA COLLECTION AND PROCESSING SYSTEM, SUCH AS FOR ELECTRIC, GAS, AND WATER UTILITY DATA," which are herein incorporated by reference.

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FIELD OF THE INVENTION

The present invention relates to automatic meter reading systems and, more particularly, to the communication protocol used for the endpoint to reader hop in the automatic meter reading system.

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BACKGROUND OF THE INVENTION

Current automatic meter reading (AMR) systems are significantly limited in the information that can be obtained from the meter. Generally, the AMR system comprises a reader and an endpoint that is interfaced to a meter. In a typical system, the endpoint obtains the

15   consumption reading from the meter and then bubbles up every few seconds to send that consumption reading, via RF signal, to the reader. Alternatively, the endpoint receives a wake-up tone from the reader that prompts the endpoint to send the consumption reading to the reader.

All that is obtained from this configuration is a single consumption reading from the meter and that reading is based on what meter register the endpoint was programmed with

20   initially at the factory.

As such, there is a need for an AMR system that enables the user of the system to have more access to and more control over the information that the meter and endpoint can provide.

SUMMARY OF THE INVENTION

The present invention is a data communication protocol used between an endpoint and a reader in an automatic meter reading (AMR) system. The communication protocol enables the

5   reader to have a conversation with the endpoint in that the reader can tell the meter what to do, it can reconfigure the meter, it can tell the endpoint to reconfigure the meter, it can request a specific response, it can request the endpoint to reprogram certain values in both the endpoint and the meter, it can request that the end point get specific information from the meter, return it to the end point, which returns it to the reader.

10   In the preferred embodiment of the present invention, a reader wirelessly communicates with both battery-powered receivers and electrically-powered receivers; each receiver being operably connected to a utility meter. Each battery-powered receiver has a bubble-up period of X seconds while each electrically-powered receiver has a bubble-up period of Y seconds. The reader reads the electrically-powered receivers every W minutes, however, only $(Y/X)*100\%$ of

15   the battery-powered receivers are bubbled up during this read time. The result is a $(1-(Y/X))*100\%$ reduction in falsing of battery powered meters producing a great savings in battery life.

On average then, the electrically-powered meters are read $1440/W$ times per day while the battery-powered meters are read only $(Y/X)*(1440/W)$ times per day. The read time

20   established within the reader is continuously sequenced by $+Y$ seconds until $+X$ seconds from a nominal. At each sequenced read time, the reader bubbles up a different $(Y/X)*100\%$ of the battery-powered receivers with which the reader may communicate. The AMR system described

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enables battery-powered receivers and electrically powered receivers to communicate on the same frequency channels with the reader.

BRIEF DESCRIPTION OF THE DRAWINGS

5   Fig. 1 depicts a radio-based automatic meter reading system that utilizes the data communication protocol of the present invention.

Fig. 2 is a table containing the physical layer specifications of the reader.

Fig. 3A is a table containing the physical layer specifications of the endpoint at data rate 1.

10   Fig. 3B is a table containing the physical layer specification of the endpoint at data rate 2.

Fig. 4 is a table containing the physical layer specifications of the endpoint in a one-way AMR system.

Fig. 5 is a diagram of a Manchester encoding structure.

Fig. 6 is an example of a Sequence Inversion Keyed Countdown Timer.

15   Fig. 7 diagrams the data packet structure.

Fig. 8 diagrams a high power pulse data packet structure.

Fig. 9A diagrams a two-way command and control frame.

Fig. 9B diagrams a one-way command and control frame.

Fig. 10 is a table containing universal command types for the data communication

20   protocol of the present invention.

Fig. 11 is a table containing type specific commands for the data communication protocol of the present invention.

Fig. 12 diagrams command 48 of the data communication protocol, Multiple Ungrouped Endpoint Command.

Fig. 13 diagrams command 49 of the data communication protocol, Vector and Listen Frame.

5   Fig. 14 diagrams command 50 of the data communication protocol, Multiple Commands to Individual Endpoint.

Fig. 15 is a diagram of the channel spectrum of the system.

Fig. 16 is an example of a timing diagram for a staged wakeup sequence for a three cell reuse pattern.

10   Fig. 17 is an example of a three-cell cellular reuse pattern.

Fig. 18 is an example of a four-cell cellular reuse pattern.

Fig. 19 is an example of a five-cell cellular reuse pattern.

Fig. 20 depicts mobile operation of the system over five channels.

Fig. 21 depicts coverage rings.

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DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention is a data communication protocol for automatic meter reading (AMR) systems. The protocol is designed to be flexible and expandable enabling both one-way and two-way meter reading in both fixed and mobile meter reading systems.

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I. System Components

In an AMR system 100, as depicted in Fig. 1, that is utilized with the present invention, the components generally include a plurality of telemetry devices including, but not limited to, electric meters 102, gas meters 104 and water meters 106. Each of the meters may be either electrically or battery powered. The system further includes a plurality of endpoints 108, wherein each corresponds and interfaces to a meter. Each of the endpoints 108 preferably incorporates a radio receiver/transmitter, e.g., the Itron, Inc. ERT. The system additionally includes one or more readers that may be fixed or mobile, Fig. 1 depicts: (1) a mobile hand-held reader 110, such as that used in the Itron Off-site meter reading system; (2) a mobile vehicle-equipped reader 112, such as that used in the Itron Mobile AMR system; (3) a fixed radio communication network 114, such as the Itron Fixed Network AMR system that utilizes the additional components of cell central control units (CCUs) and network control nodes (NCNs); and (4) a fixed micro-network system, such as the Itron MicroNetwork AMR system that utilizes both radio communication through concentrators and telephone communications through PSTN. Of course other types of readers may be used without departing from the spirit or scope of the invention. Further included in AMR system 100 is a head-end, host processor 118. The host processor 118 incorporates software that manages the collection of metering data and facilitates the transfer of that data to a utility or supplier billing system 120.

The AMR system 100 and the data protocol is usable in both one-way meter reading and in two-way meter reading. The one-way meter reading system enables the reader to communicate with and command the endpoint while the two-way meter reading system enables the reader to communicate with and command the endpoint while also enabling the endpoint to respond to the reader.

II. System Protocol

The present communication protocol will be described with reference to the 1430 MHz

band that may be utilized within North America, however, it should be understood that any other

5   radio frequency band may be used, as suitable, without departing from the spirit or scope of the

invention. The present communication protocol will also be described with reference to the

Open Systems Interconnection (OSI) protocol stack of the International Standards Organization

which includes: (1) the physical layer; (2) the data link layer; (3) the network layer; (4) the

transport layer; (5) the session layer; (6) the presentation layer; and (7) the application layer.

10

II.A. System Protocol – Physical Layer

The physical layer describes the physical characteristics of the communication. This

layer conveys the bit stream through the network at the electrical and mechanical level. It

provides the hardware means of sending and receiving data on a carrier. The physical layer

15   specifications for the reader may be found in Fig. 2 wherein: (1) the operational modes; (2) the

frequency band; (3) the channel bandwidth; (4) the modulation scheme; (5) the deviation; (6) the

encoding; (7) the bit rate; (8) the frequency stability; (9) the minimum reception sensitivity; (10)

the transmission power; (11) the preamble length; and (12) the transmission modes are provided.

The physical layer specification for the endpoint in a two-way AMR system, at a first

20   data rate and a second data rate, are found in the tables of Fig. 3A and Fig. 3B, respectively. The

specifications provided include: (1) the operational modes; (2) the frequency band; (3) the

channel bandwidth; (4) the modulation scheme; (5) the deviation; (6) the encoding; (7) the bit

rate; (8) the frequency stability; (9) the minimum reception sensitivity; (10) the minimum preamble length; and (11) the factory default frequency. The physical layer specification for the endpoint in a one-way AMR system is provided, similarly, in the table of Fig. 4.

5   II.B. System Protocol – Data Link Layer

The data link layer specifies how packets are transported over the physical layer, including the framing, i.e., the bit patterns that mark the start and end of packets. This layer provides synchronization for the physical level. It furnishes transmission protocol knowledge and management. In the present data communication protocol, all outbound data transmissions,

10   i.e., all communications from the reader's central radio to endpoint, are Manchester encoded with the guaranteed transition mid-bit and each data bit encoded as $a_n a_n(bar)$. (See Fig. 5 for the Manchester Encoding Structure). Inbound transmissions from the endpoint are either transmitted as Manchester encoded data, identical to outbound transmissions, or are transmitted as NRZ (non-return to zero) data. Selection is based on the value of the MCH flag in the command and

15   control frame.

The data link layer provides a countdown timer. The countdown timer uses Sequence Inversion Keying to represent timer bits. Each system is assigned a 10-bit pseudo noise (PN) sequence (for valid sequences, see Table 1 below). That sequence in the data stream represents a timer bit value 0 and the inverse of that sequence in the data stream represents a timer bit value

20   1. Timer values are composed of 10 timer bits, or 100 data bits. The countdown timer begins at 1023, or 1111111111 binary, and counts sequentially to zero, encoding all timer bits as either the system PN sequence or its inverse. The total counter time, in seconds, is 102400/r, where r is the

bit rate, in bits per second. Fig. 6 provides an example of a Sequence Inversion Keyed

Countdown Timer.

Table 1. PN Sequences

Sequence Number	Usage	Sequence=0	Inverted Sequence=1
0	Factory Default	0000000010	1111111101
1	Electric Devices	0000000110	1111111001
2	Electric Devices	0000001010	1111110101
3	Electric Devices	0000001110	1111110001
4	Electric Devices	0000011010	1111100101
5	Electric Devices	0000010110	1111101001
6	Electric Devices	0000111010	1111000101
7	Battery Devices	0000101110	1111010001
8	Battery Devices	0001110110	1110001001
9	Battery Devices	0001101110	1110010001
10	Battery Devices	0000011110	1111100001
11	Battery Devices	0001011110	1110100001
12	Battery Devices	0001111010	1110000101

All inbound packet transmissions are preceded by a 24-bit preamble and appended with a 16-bit

CRC code, which is inclusive of all header information, but not the preamble, length, or

length_bar bytes. The CRC polynomial is 0x1021. The CRC initialization value is 0x0000.

CRC processing is performed most significant byte (MSB) first, and the final checksum is not

inverted.

II.C. System Protocol – Network Layer

The network layer specifies how packets get from the source network to the destination network. This layer handles the routing of the data (sending it in the right direction to the right destination on outgoing transmissions and receiving incoming transmissions at the packet level). The network layer does routing and forwarding. In the present data communication protocol, the

5   network layer functionality is only implemented in electric endpoints, i.e., it is not used for battery-powered endpoints, or in any endpoint that acts as translator or repeater. This layer controls the hopping functions that need to occur between a reader and any endpoint in order to transfer data. This hopping protocol is currently used within the Itron AMR systems and is therefore not described in detail herein.

10

II.D. System Protocol– Transport Layer

The transport layer is used to solve problems like reliability ("did the data reach the destination?") and ensure that data arrives in the correct order. This layer manages the end-to-end control (for example, determining whether all packets have arrived) and error-checking. It

15   ensures complete data transfer. In the present data communication protocol, slotting control is handled in the transport layer. This includes slot assignments, timing, and any necessary packetization. Fig. 7 details the packet structure. The message, message type, and flags are received from the presentation layer, and broken into appropriately sized packets. Each packet is prefaced with the packet number, ID, flags, message type, and packet length. The packet length

20   reflects the number of bytes in the message itself, exclusive of header information. In the case where more than 254 bytes are required in a packet, the value of the length field is set to 0xFF, and the actual length of the message structure is placed in bytes 14 (high byte) and 15 (low byte),

with the message bytes to follow. All packets must have a whole number of bytes in the message.

The packet number byte is configured as below in Table 2, wherein the first four bits comprise the total number of packets in this message and the last four bits comprise the packet

5   number.

Table 2. Packet Number

T	T	T	T	N	N	N	N
MSB							LSB

10

The flags byte is configured as below in Table 3. The first two bits are reserved while the second two bits provides the encoder number (for multi-encoder units), wherein 00 = encoder 0, 01 = encoder 1, 10 = encoder 2, and 11 = encoder 3. The fifth bit signifies the status of a pending event, wherein 0 = no pending event and 1 = a pending event. The sixth bit comprises

15   the security bit, wherein 0 = security disabled and 1 = security enable. The seventh bit comprises the relay bit, wherein 0 = message from originating endpoint and 1 = message via relay. The eighth bit comprises the resend bit, wherein 0 = first attempt at packet transmission and 1 = resend attempt.

20   **Table 3. Flags**

R	R	ENC	ENC	EVT	SEC	RLY	RSD
MSB							LSB

Some endpoints in the system have the option of sending out an infrequent (several times

25   a day) fixed format message at a higher power level, for use in one-way fixed network

applications. The message has its own structure, as defined in Fig. 8. The custom packet is then

BCH (255, 139, 15) encoded, prior to transmission. The encoding polynomial is

$0x461407132060175561570722730247453567445_8$. For multi-encoder endpoints this packet is

generated and sent for each individual encoder. The flags for the high power pulse data packet

5 structure are configured as shown in Table 4 below. The first four bits are reserved while the

fifth and sixth bits provide the encoder number, wherein 00 = encoder 0, 01 = encoder 1, 10 =

encoder 2, and 11 = encoder 3. The seventh bit comprises the relay bit, wherein 0 = message

from originating endpoint and 1 = message via relay. The eighth bit comprises the error code

indicating that a critical endpoint error has occurred.

10

Table 4. Flags

R	R	R	R	ENC	ENC	RLY	ERR
MSB							LSB

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II.E. System Protocol – Session Layer

The session layer sets up, coordinates, and terminates conversations, exchanges, and

dialogs between the applications at each end. It deals with session and connection coordination.

In the present data communication protocol, the session layer generally comprises the command

20 and control frame that is sent from the reader to the endpoint.

II.E.i. System Protocol – Session Layer/Two-Way Command and Control

The command and control frame is used to issue command to two-way endpoints either individually or in groups. It also serves to realign the endpoint real-time clock. Fig. 9A diagrams the two-way communication command and control frame. As shown, the command and control frame transmission is preceded by a 24-bit preamble, as indicated by the three "P"

5   fields within the frame. The first 16 bits are preferably an alternating pattern, AAAAh, and are used for clock recovery. The last 8 bits are used for frame and timing synchronization.

Field "0" of the command and control frame comprises the system identification (ID). Each system is issued an 8-bit ID value, which is stored in the endpoint, to distinguish different systems within geographic proximity. The endpoints are designed to respond to commands from

10   their own system or to commands that address them specifically by ID number, proper security password, and have a 0x00 in field "0". The system ID functions nearly identically to the cell ID, described below. However, the system ID is universal, while the cell ID is local, i.e., a single system will have multiple cells each having the same system ID but a different cell ID.

Field "1" of the command control frame comprises the frame ID. Each reader within the

15   system is assigned a frame ID to use based on its position in the wake-up sequence. The position in the wakeup sequence is directly related to the frequency reuse pattern that is used in a given system. Table 1, described earlier, correlates the frame ID to the channel, which is correlated to the cell reuse ratio.

Field "2" of the command and control frame comprises the cell ID. Each cell is issued an

20   8-bit ID value, which is stored in the endpoint, to distinguish different systems within geographic proximity.

Fields "3" through "6" of the command and control frame is the RTC, which is defined as UTC time (coordinated universal time), which is a 32-bit value representing the number of seconds since midnight (00:00:00) on January 1, 1970 GMT.

Field "7" is the command flags 1 field, wherein the first three bits define a slot length according to Table 5.

TABLE 5. Slot Lengths

Value of Length Bits	Nominal Length in Ticks*	Nominal Length in ms
000	819	24.99390
001	1638	49.98779
010	3277	100.00610
011	6553	199.98169
100	9830	299.98780
101	16384	500.00000
110	32768	1000.00000
111	163840	5000.00000

*Defined as ticks of an ideal 32,768 Hz clock.

The fourth bit is the forward error correction bit, wherein 0 = no forward correction error and 1= forward error correct all responses. The fifth bit provides the slot mode, wherein 0 = respond to command in pseudo-random slot (Slotted Aloha) and 1 = respond to command in the defined slot. The sixth bit of field "7" defines the data type, wherein 0 = NRZ response from endpoint and 1 = Manchester encoded from the endpoint. The seventh and eighth bits of field "7" comprise the command target, wherein 00 = the entire cell, 01 = the group defined in EPID_HI (field "12"), 10 = the group defined in EPID_LO (field "15"), and 11 = the endpoint defined by EPID (including HI/LO), fields "12" through "15". It should be noted that in single endpoint communications the command target (TGT) is set to 11 and the endpoint responds immediately

after command processing with a minimum of 25 milliseconds between this frame and the endpoint response.

Field "8" of the command and control frame is the command flags 2 field, wherein the first four bits are reserved. The fifth and sixth bits defined the encoder number, wherein 00 = Encoder 0, 01 = Encoder 1, 10 = Encoder 2, and 11= Encoder 3. The final seventh and eighth bits define the transmit mode, wherein 00 = transmit mode 1, e.g., mobile response required, 01 = transmit mode 2, e.g., fixed network response required, and 10/11 are reserved. Also see section V below.

Field "9" of the command and control frame comprises the slot offset. Slot offset defines the number of slots between packets in multi-packet messages. For example, if the endpoint has an initial slot number of 50, and the slot offset is 120, a three-packet message would be transmitted in slots 50, 170, and 290.

Fields "10" and "11" of the command and control frame define the first unsolicited message. Specifically, they define the slot number where the unsolicited messages (UMs) are to begin. Any UMs generated during the cell read would be reported in a pseudo-randomly selected slot after the slot defined here. If the value of this field is 0x0000, no UMs are sent from the endpoint.

Fields "12" through "15" of the command and control frame provide the endpoint IDs for those endpoints that the reader is desiring to communicate with.

Fields "16" and "17" are the security fields and are described further in relation to the presentation layer.

Field "18", defines the command set. The commands are divided into two groups: (1) universal and (2) type-specific. Universal commands are numbered 0-63 and are applicable to all the system endpoints. Type specific commands are numbered 64-255 and vary depending on the lower nibble of the command set field in accordance with Table 6 below.

5

Table 6. Command Sets

Command Set	CDS Value	Usage
0 (default)	0000	Utility Metering Endpoints
1	0001	Repeaters and Translators
2	0010	Telemetry Devices
3-14	0011-1110	<<Reserved>>
15	1111	<<Reserved Engineering Use Only>>

10   Fields "19" through "21" of the command and control frame define the command and command body. Specifically, the eight command bits of field "19" indicate the command type, wherein the numbers 0-63 are universal commands and 64-255 are the type specific commands. Fields "20" and "21" provide sixteen bits wherein any data needed to carry out the command type is provided. The tables in Figs. 10 and 11 indicate the command types and command bodies

15   that are possible with the system of the present invention. Referring to the universal commands (Fig. 10), it can be seen that the present system is capable of but not limited to: (1) reporting a status; (2) changing a system number to a new system number; (3) changing a group number to a new group number; (4) changing a system slot number to a new system slot number; (5) changing the cell ID to a new cell ID; (6) reporting slot numbers; (7) resending identified packets

20   of data; (8) setting the receiver bubble-up period; (9) setting the bubble-up channel; (10) setting

the bubble-up time; (11) configuring the transmission power; (12) setting the channel frequency; etc.

Referring to the type specific commands (Fig. 11), numerous other commands are available including but not limited to: (1) reporting consumption data; (2) reporting time of use (TOU) data; (3) reporting logged data; (4) reporting temperature; (5) reporting tamper data; (6) setting configuration flags; (7) initializing consumption; (8) reporting an event summary; (9) performing an endpoint diagnostic check; (10) reporting memory contents; etc.

Fields "22" and "23" of the command and control frame designate the response frequency for the endpoint. The response frequency is configured as 16 bit flags, identifying valid response frequencies for the endpoint. For example, if the response frequency has a value of 0x00C1 (bits, 7, 6, and 0 are set), the endpoint may respond on channel 7, channel 6, or channel 0.

Fields "24" and "25" are reserved for later use.

Fields "26" and "27" of the command and control frame provides the cyclic redundancy check (CRC). Specifically, fields "26" and "27" provide a 16-bit CRC. The CRC is preferably a polynomial defined as 0x1021. The CRC initialization value is 0x0000. CRC processing is performed most significant bit (MSB) first, and the final checksum is not inverted.

II.E.ii. System Protocol – Session Layer/One-Way Command and Control

One-way devices use the programming frame shown in Fig. 9B. The command and command body bytes are similar to that described above with reference to the two-way devices. The byte for number of commands provides the total number of commands to follow in this

frame, with a maximum value of 8. The command flags are diagrammed in Table 7 below. The

first two bits indicate the transmit mode, wherein 00 = transmit mode 0, 01 = transmit mode 1,

and 10/11 are reserved. The third bit designates the data logging, wherein 0 = data logging is

disabled and 1 = data logging is enabled. The fourth bit designates the forward error correction,

5   wherein 0 = disable forward error correction on response and 1 = enable forward error correction

on response. The fifth and sixth bits designate the mode set, wherein 00 = stock mode, 01 = test

mode, 10 = reserved mode, and 11 = normal mode. The seventh and eighth bits are reserved.

Table 7. Command Flags

10

TXM	TXM	DLG	FEC	MDE	MDE	R	R
MSB							LSB

II.E.iii. System Protocol – Session Layer /Special Commands – Channel Frequency

15   Certain of the commands provided in the command and control frame are described in

detail below. For instance, Command 33, which is the set channel frequency. Each of the

system endpoints support up to 16 channels, which are set individually. They may or may not be

contiguous channels. The channel numbering differs based on frequency band. For example, in

the present implementation of the invention, the 1427 – 1432 MHz band is divided into 6.25 kHz

20   frequency channels, with frequency channel 0 centered at 1427.000 MHz, frequency channel 1

centered at 1427.00625 MHz, etc. If endpoint channel 15 is programmed to a value of 480, that

endpoint receiver will always operate at 1427.000 + (.00625 * 480) = 1430.000 MHz.

          The command body of the set channel frequency command is detailed below in Table 8:

25

TABLE 8. Command Body/Channel Frequency

CHN	CHN	CHN	CHN	FRQ	FRQ	FRQ	FRQ	FRQ	FRQ	FRQ	FRQ	FRQ	FRQ	FRQ	FRQ
MSB															LSB

5   Individual frequencies are programmed into the endpoint by selecting the channel being

programmed (1-15) with the top nibble, and the frequency number in the lower 12 bits. Endpoint

channel 0 is preferably the manufacturing default frequency, and may not be edited. Endpoint

channel 15 is the receiver frequency. It is initialized to the same frequency as channel 0 at

manufacture, and is preferably programmed prior to or at installation. The endpoint channel uses

10   are defined in Table 9 below:

Table 9. Endpoint Channel Use

Endpoint Channel	Channel Use
0	Factory Default. This channel is not reprogrammable.
1	General use Tx/Rx (Transmission/Reception)
2	General use Tx/Rx
3	General use Tx/Rx
4	General use Tx/Rx
5	General use Tx/Rx
6	General use Tx/Rx
7	General use Tx/Rx
8	General use Tx/Rx
9	General use Tx/Rx
10	General use Tx/Rx
11	General use Tx/Rx
12	General use Tx/Rx
13	General use Tx/Rx
14	Default UM Channel (unsolicited message)
15	Default Rx Channel

15

The configuration flag commands, i.e., commands 90, 91, and 92 are used for setting individual flags in the endpoints. Each flag command includes an 8-bit flag mask and an 8-bit flag as shown below (the configuration flags 1 command body):

5 **Table 10. Flag Mask**

MSK	MSK	MSK	MSK	MSK	MSK	MSK	MSK
MSB							LSB

10 **Table 11. Flags**

R	R	R	R	UMC	FN	FEC	MMI

The flag mask field determines which flags are to be modified by this command. A "1" in any bit position means the associated value in the flags field should be modified. For example, A

15 value of 0x17 (bits 4,2,1 and 0 are high) means that the values in the Flags field, bits 4, 2, 1, and 0 must be written to the associated flags in the endpoint. With regard to the flags field of Table 7, the first four bits are reserved for future growth while the fifth bit, UMC, defines the unsolicited message channel, i.e., UMC = 0 then transmit UMs on Channel 14, and UMC = 1 then transmit UMs on channel 15. The sixth bit of the flags field defines the fixed network

20 mode, wherein 0 = this endpoint operates in Mobile/Handheld mode only and 1= this endpoint operates in mobile/handheld/fixed network mode. The seventh bit of the flags field defines the forward error correction, wherein 0 = no forward error correction applied to the high power pulse and 1 = forward error correction is applied to the high power pulse. The eighth bit of the flags field defines the multiple message integration, wherein 0 = no multiple message integration

25 applied to high power pulse and 1 = multiple message integration applied to high power pulse.

II.E.iv. System Protocol – Session Layer/Special Commands – Test Commands

The present data communication protocol provides at least two commands for use in system testing and analysis. The first command is command 210, i.e., Generate UM (unsolicited message). This command automatically generates an unsolicited message in all endpoints

5   addressed by the command and control frame. It generates the lowest numbered UM supported by the endpoint. The second command is command 211, i.e., Enter Screaming Viking Mode. Screaming Viking Mode is a constant transmission mode, to be used for test only. When this command is received, the endpoint repetitively transmits its ID for the number of minutes declared in the command. If a value of 0 is sent, the mode is active for 15 seconds.

10

II.E.v. System Protocol – Session Layer/Special Commands – Extension Commands

Commands 48, 49 and 50 of the data communication protocol are implemented as extensions to the command and control frame. The extension commands immediately follow the command and control frame in the same transmit session. Command 48 is the multiple

15   ungrouped endpoint command. In the case where the system needs to command a group of specific endpoints and vector them to specific slots, command 48 is issued. The central radio then issues commands to these endpoints, as shown in Fig. 12. This command can be used to address a maximum of 16 distinct endpoints. The packet length reflects the number of endpoints addressed by the message. Note that the command 48 may not be used for any command that

20   requires the security password. The structure of command 48 provides for an 8-byte preamble having the value of 0xAAAA AAAA AAAA AA96, the length, the endpoint IDs, and the

command bodies for each of the endpoints and a response byte for each of the endpoints. The

response byte is diagrammed in Table 12 below:

Table 12. Response Byte

R	R	R	R	CHN	CHN	CHN	CHN
MSB							LSB

5

The response byte reserves the first four bits and utilizes the last four bits to define the response

frequency nibble. Specifically, the four bit flags define which of the four default channels the

10   endpoint may respond on. If CHN = 0000, then use the response frequency byte from the

original command and control frame. The structure of the command 48 also includes the CRC as

described earlier.

Command 49, i.e., the vector and listen frame, is issued in the instance where the central

radio or reader need to download an arbitrary block of data to the endpoint. The endpoint, upon

15   receiving this command receives a data frame, as defined in Fig. 13. This command is valid only

when the endpoints are individually addressed (i.e., TGT = 11). The data is endpoint-type

specific. Note that the vector and listen frame has an 8-byte preamble with a value of 0xAAAA

AAAA AAAA AA96. Further, note that the packet length reflects the number of bytes in the

message itself, exclusive of header information, and that the CRCs computed over all bytes in

20   the message body.

Command 50, the multiple command to individual endpoint command, is used in the case

where the central radio or reader need to download a series of commands to one specific

endpoint. The endpoint, upon receiving this command, receives a data frame as defined in Fig.

14. This command is only valid when the endpoints are individually addressed (i.e., TGT = 11). Up to 24 commands may be issued to an endpoint using this structure. Note that the packet length reflects the number of commands to be issued within this structure.

5   II.F. System Protocol – Presentation Layer

The presentation layer, which is usually part of an operating system, converts incoming and outgoing data from one presentation format to another and it is sometimes called the syntax layer. In the present data communication protocol, the presentation layer handles data security and any necessary data compression and decompression.

10   The data security is preferably a simple two-level protocol, which may be enabled or disabled by the customer. Level 1 provides simple encryption for the transfer of normal data while level 2 provides write security to the endpoint to prevent unauthorized users from changing endpoint parameters.

Level 1 is intended for use on ordinary data being transmitted from the endpoint to the

15   head end. All data is encrypted with a simple 8-bit XOR mask. The level 1 security enables flag and encryption mask and are editable by a level 2 parameter write. The factory default for the XOR mask is the bottom 8 bits of the serial number. Level 1 security is applied only to the message itself and not to the EPID, flags, or message type. Level 1 security may be disabled by setting the mask value to 0.

20   Level 2 security is intended for use on any head end commands to change endpoint parameters. It includes modification of operational, security and reprogramming parameters. Level 2 functionality is independent and can be applied with or without Level 1 functions

enabled. Each endpoint has a 16-bit password. This password is originally defined at install, and can be edited by a valid Level 2 command. Any write command must include the current password to be considered valid by the endpoint. For added security, the Level 1 encryption mask may be applied to the password, if Level 1 functionality is active. There is no compression

5   performed on packet data.

II.G. System Protocol – Application Layer

The application layer is the layer at which communication partners are identified, quality of service is identified, user authentication and privacy are considered, and any constraints on

10   data syntax are identified. (This layer is *not* the application itself, although some applications may perform application layer functions.) In the present data communication protocol, an endpoint application layer is used in conjunction with the application programming interface (API). When data is requested by the presentation layer, via the API, the application layer performs its processing and returns the requested message as a single block, along with one 8-bit

15   value. The value represents the message type.

III. System Operation

The two-way AMR system of the present invention, at 1430 MHz, is designed to operate most efficiently in five contiguous RF channels. This allows the use of a cheaper (wider)

20   receiver section in the endpoint while still maintaining the FCC mandated 50 KHz maximum transmit spectrum. The transmit spectrum in all devices, endpoints, and readers, must maintain a 50 KHz or less occupied bandwidth during transmit. The receiver in the reader must also have a

good selectivity on the channel of interest. The endpoint receiver is allowed to accept a wider receive bandwidth primarily to reduce the cost of the endpoint.

Refer to Fig. 15 to observe the 250 KHz of spectrum allocated to the system. As shown, the spectrum is divided in to five 50 KHz channels. The center channel, i.e., channel 3, is

5   designated as the control channel for the system 100. All endpoints 106 listen on this channel. As such, if the readers are quasi-synchronized in their outbound transmissions the center channel approach allows the endpoints to use a wider receive bandwidth while avoiding the interference that would normally be a problem (synchronization is described in further detail below). The diagram of Fig. 15, illustrates the bandwidth differences graphically. Since the reader has good

10   selectivity the endpoints can respond on a different channel in each cell simultaneously allowing the maximum data throughput in the system (cell re-use is described in further detail below).

By utilizing an appropriate RF ASIC, e.g., the Karate RF ASIC, the architecture can be reduced to three contiguous channels with the reaming two or more channels scattered throughout the band to ease spectrum allocation requirements. With a reduction in the

15   interference protection to the end point, a completely separated channel model could be used in an alternative configuration. However, in the separate channel model, the endpoint requires additional base band filtering and is still slightly more susceptible to adjacent channel interference on the control channel especially if operating in the high power portion of the band. The separate channel option also allows multiple control channels in the system when mobile

20   operation is used with multiple outbound channels. When using the separate channel model, channels 2 and 4, of a 5-channel block, are used for control signals.

To alleviate cell-to-cell interference in a system with a single control channel the readers must be synchronized in time so that the control frames, which are described in further detail below, do not overlap. The addition of "dead time" in between sequential control frames allow for the receivers to be quasi-synchronized instead of in perfect lock step. In the preferred embodiment, quasi-synchronized means that the receivers are within 0.5 seconds of each other, which can easily by achieved via protocols such as NTP (network time protocol). Other quasi-synchronization times may be used without departing from the spirit or scope of the invention. As such, a GPS or other high accuracy time base is not required within the readers.

Within the AMR system, each reader is assigned a frame ID to use based on its position in a wakeup sequence. The position in the wakeup sequence is directly related to the frequency reuse pattern used in a given system. The timings in the diagram of Fig. 16 are provided as an example of a staged wakeup sequence for three cell reuse. As shown, the timings are for an endpoint to endpoint clock accuracy of +/- 0.5 seconds, if the value obtainable is only +/- 1 second then the dead time must be increased to 5 and the nominal frame time to 22.5 seconds. All other timings remain the same. If GPS is available in the reader, the dead time can be reduced and the time frame timing can be shortened. In any case, the minimum dead time is preferably 0.5 seconds.

As shown in Fig. 16, the first wake-up sequence is initiated at time T=0. For the first 18.5 seconds, get wakeup (SIK countdown timer), next 0.25 seconds (command and control, frame 2), and last 2.5 second is dead time. The remaining time in the timeline is the hold off time for response slots, which is the frame number * the nominal frame time, or 2*20 = 40 seconds of hold off time. At T=20, the second wake-up sequence is initiated. Similarly, the first

18.5 seconds, get wakeup (SIK countdown timer), next 0.25 seconds (command and control, frame 1), and the last 2.5 seconds is dead time. The hold off time for response slots in this instance is, again, the frame number * the nominal frame time, which is 1*20 = 20 seconds off hold off time. At T=40, the third wake-up sequence is initiated. For the first 18.5 seconds, get

5   wakeup (SIK countdown time), the next 0.25 seconds (command and control, frame 0), and the last 2.5 seconds is dead time. The hold off time for response is calculated as follows, frame number * nominal frame time, or 0*20 = 0 seconds hold off time meaning the endpoints have 2.5 seconds before the beginning of slot 0 in this cell.

As mentioned, the example of Fig. 16 is for a three cell reuse pattern. However, the

10   example can be easily extended to higher cellular reuse ratios by adding more frames as appropriate. In the 1430 MHz system, the maximum recommended cellular reuse is 5. This leads to a hold off time of 100 seconds in the first cell transmitted which is short enough for the endpoint to maintain accurate timing with regard to slot timings.

Unless otherwise specified by the system, the frame ID is preferably tied to the cellular

15   frequency used based on Table 13 below:

Table 13. Frame ID

Cell Reuse Ratio	Channel to Frame ID mapping
3 Cell	Channel 1 = Frame ID 0 Channel 3 = Frame ID 1 Channel 5 = Frame ID 2
4 Cell	Channel 1 = Frame ID 0 Channel 2 = Frame ID 1 Channel 4 = Frame ID 2 Channel 5 = Frame ID 3
5 Cell	Channel 1 = Frame ID 0 Channel 2 = Frame ID 1 Channel 3 = Frame ID 2 Channel 4 = Frame ID 3 Channel 5 = Frame ID 4

5   To maximize throughput in the system 100, a cellular reuse scheme is employed in the 1430 MHz band. The reuse ratio is preferably a 3, 4, 5, 7, or 9 cell pattern. Smaller patterns are preferred from a delay perspective, however, the final choice is preferably made during the RF planning and installation of actual systems in the field. The 7 and 9 patterns are preferably used in the virtual cell model. The reuse patterns are provided in Figs. 17, 18, and 19 depicting three-

10   cell (ABC), four-cell (ABCD), and five-cell reuse patterns (ABCDE), respectively.

IV. Mobile and Hand-Held Operation

When operating in the mobile or hand-held mode, the 2.5 seconds of "dead time" does not apply. Rather slot "0" occurs at the end of the command and control frame plus 25

15   milliseconds. Note, that due to time required to read the attached meter and/or bring the charge pump to full operation the endpoint may or may not respond in slot "0" even if told to respond immediately.

In programming mode, the hand-held control may reduce its sensitivity by as much as 30 dB to avoid overload conditions at close programming distances. The hand-held and endpoint must work with programming distances as close as 0.5 meters and as far as 300 meters when in the mobile mode of operation with a line of site propagation path.

5   In mobile operation the wake-up sequence, the command & control data, and the receive portions of a standard read cycle are continuously repeated as the mobile moves through the system. The timing is preferably in the range of a one to five second cycle. The diagram depicted in Fig. 20 gives a general over view of the mobile operation over the five channels.

The command & control frame preferably contains a group call read that solicits a

10   consumptive type reading from all of the endpoints that can hear the mobile and that have the correct system ID. The endpoint responds to the group call in a random slot, on a random channel. The random channel is chosen from the list of available channels that is provided in the command & control frame. The random slot is one of the 50 ms slots in the Slotted-ALOHA portion of the frame. (Slotted ALOHA is a random access scheme just like regular ALOHA

15   except that the transmissions are required to begin and end within the predefined timeslot. The timeslots are marked from the end of the command & control frame just like in the fixed network).

When the reader hears a response from a given endpoint, it knows that it is within range and can request a specific response from the endpoint in the next command & control frame.

20   The command & control frame is expected to contain both a standard command frame and an extended control frame to allow for the mobile to access the most endpoints possible in a single pass. When the mobile requests a response from the end point it will tell it the channel and time

slot that it is supposed to respond on. This is to minimize the chances of a collision on the longer messages that can be delivered in the MDP type of responses. During the mobile cycle, battery endpoints may be required to bubble up their receivers up at a higher rate than normal or synchronize to the first command & control frame to improve mobile performance.

5   If the van is moving at a maximum of 30 miles per hour it will travel 440 feet in 10 seconds. The van will also have a communications radius of approximately 500 feet give a 1400 MHz system operating at a data rate of 22.6 Kchips/second, with the expected power levels and receiver sensitivities (e.g., +14 dBm endpoint TX power, -110 dBM RX sensitivity in the van, 20 dB margin, endpoint at 5'). The margin is included because the MDP data packet is much longer

10   than the current SCM type messages and is not repeated unless an error occurs. To achieve a low re-try rate, it is desirable to bring the BER down to 0.01%. To do this under normal situations would require an additional 20 dB of margin, however, a diversity setup on the van receivers can be used to achieve the same results. This requires two antennas on the van placed five to six feet apart along with an additional receiver demodulator chain per channel. For SCM

15   data that is repeated multiple times, the system can operate at a much lower margin and still achieve excellent read reliability in the van. A coverage radius of about 1200 feet is obtained for the system when collecting standard consumptive data.

        The diagram of Fig. 21, shows the coverage rings for low margin SCM messages and for the 20 dB margin IDR messages for the present system in comparison with the current 0 dB

20   margin SCM messages from the ERT.

        With the current mobile protocol each endpoint is, on average, in the range of the van for approximately 12 to 25 seconds. This is an appropriate amount of time to wake up the endpoint,

30

identify who it is, request an MDP (mobile data packet = 250 bytes of raw data maximum) to be sent, receive the MDP and potentially retry the request and receive portions of the process if necessary.

In the basic system, there are five channels at a maximum 75% utilization for MDP responses. This gives an effective data rate of 42375 BPS or 5296 bytes per second or 21 blocks per second. Since the system is looking at a single block per meter, the system can support 21 new meters per second. The mobile then has a nominal range of 500 feet. This gives the system of about 175 meters in range at any given time, even in the densest specified systems. If the van is moving at 30 mph, the system gets 44 feet of new meters per second. In performing a geometric approximation, the result is about 12 new meters per second. So, the system can handle 21 new meters per second but can only get in the range of 10 to 12 meters per second. This allows for a full set of retries in a dense system. (This assumes the low 11.36363 KBPS data rate and the full 250 byte MDP, for smaller packets and with the higher data rate option, the situation is even better.

V. Bubble-Up Optimization Scheme

The basic premise of using a bubble up receiver in a two-way system to conserve battery life is not new. However, it has consistently been a problem to deal with falsing, i.e., waking up the meter when there is no desire to read the meter. Current options for dealing with falsing include operating on different frequencies, operating with different data rates, operating with different modulation techniques (and, multiple frequencies may not always be obtainable in the

current regulatory environment). However, each of these solutions increases the cost and complexity of the receivers.

As such, the present invention presents a simple and cost effective approach to reducing falsing in a receive bubble up system by enabling the readers to transmit the wakeup signal for a

5   variable amount of time. Different bubble up periods are used between the electric and battery powered products and variable length wakeup preambles in the reader to reduce falsing between the systems thus increasing the battery life of the battery-powered receivers while reducing overall complexity.

The optimization scheme of the present invention requires that battery devices be set up

10   with a bubble up period of X seconds, which is much longer than the bubble up period of the electric devices, Y seconds. In general, in any AMR system, the electric devices are read much more often than battery devices. However, the desire is not to wakeup the battery devices each time the electric devices are read; this is just wasted battery lift. As such the desired scenario is to read the electric devices every W minutes and read the battery devices every Z hours. This is

15   a ratio of (Z*60)/W to 1 in read times which can be a significant amount of battery capacity over the life of the device. With the wakeup timings of Y/X of the battery devices in the system wakeup in each electric read cycle. The fixed network reader offsets the next sequential read time by +Y second which will wake up a different (Y/X)*100% of the battery population, this continues until +X seconds from nominal is reached. Then, there is a loop back to 0 seconds

20   offset and the process is started all over again. With this approach each battery device only wakes up on an average of (Y/X) * (1440/W) electric reads per day instead of all (1440/W)

reads. Basically, there is a reduced falsing by $(1-(Y/X))*100\%$ with this algorithm which is significant.

An example of the optimization scheme is provided hereinbelow: The battery devices are set to a bubble up period of 10 seconds and the electric devices to a period of 0.5 seconds. In general, the system is going to read the electrics devices much more often than the battery devices. A typical scenario is to read the electric devices every 15 minutes and read the battery devices every 12 hours. This is a ratio of 48 to 1 in read times which can be a significant amount of battery capacity over the life of the product. With the wakeup timings outlined only 0.5/10 (or 5%) of the battery devices in the system wakeup in each electric read cycle. The fixed network reader offsets the next sequential read time by +0.5 seconds which will wake up a different 5% of the battery population, this continues until the system reaches +10 seconds from the nominal at which point the system loops back to 0 seconds offset and starts the process over again. With the approach each battery device only wakes up on average of 4.8 electric reads per day instead of on all 96 reads per day. Basically, the falsing has been reduced by 95% by utilizing this scheme.

Thus, the bubble-up optimization scheme described above allows a customer to have an optimized electric/gas or electric/water (gas and water receivers are generally battery powered) combination system that gives maximum battery life in the battery products, provides maximum flexibility and data throughput in the electric devices, all the while allowing the electric and battery systems to co-exist on the same frequency channels, which enables easier FCC approval of license applications. The present invention helps to eliminate battery consumption in receiver

bubble up devices due to falsing thus allowing multiple systems to operate in the same spectrum, e.g., combination utilities.

The present invention may be embodied in other specific forms without departing from the spirit of the essential attributes thereof; therefore, the illustrated embodiment should be considered in all respects as illustrative and not restrictive, reference being made to the appended claims rather than to the foregoing description to indicate the scope of the invention.